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UNDERSTANDING OF MICROWAVE HEATING BEHAVIOUR OF LUNAR REGOLITH AND SIMULANTS. S. Lim¹, A.D. Morse¹, M. Anand¹, A. Holland¹, ¹Affiliation School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK. Email: sungwoo.lim@open.ac.uk

Introduction: The Space Instrumentation Group at The Open University are investigating microwave sintering of lunar regolith/simulant as a potential fabrication method of 3D printing on the Moon to build lunar habitats. This has enabled us to integrate our existing expertise in 3D Concrete Printing [1, 2] and knowledge of lunar science and ISRU potential on the Moon [3] to perform a series of microwave sintering experiments aiming to develop a potential fabrication method of an extra-terrestrial construction process.

As part of this initiative, we have designed an industrial bespoke microwave heating apparatus. This apparatus will allow a thorough experimental investigation of the sintering mechanism of lunar regolith/simulant in the cavity. The mechanical properties of sintered specimens produced under optimal conditions can then be explored. The experiment will also be validated using COMSOL Multiphysics simulation software. In this contribution, we discuss the first outcomes using the bespoke microwave heating apparatus, and how COMSOL has been employed to understand the different characteristics of lunar simulants when subjected to microwave heating.

Microwave sintering: Microwave sintering of lunar regolith as a potential fabrication method of lunar habitat construction has become one of the favourite topics in recent years [4]. Previous research in this area, however, have been conducted using domestic microwaves, which are not ideal for sintering lunar simulants due to (i) incapable of withstand temperatures of up to 1,250 °C – the melting point of lunar regolith/simulant; (ii) not optimised to maximise microwave energy into a single hotspot; (iii) unable to mimic lunar atmospheric condition; (iv) it is not possible to measure sample surface temperature accurately; and (v) the fixed frequency at 2.45 GHz which is an optimal frequency to heat water molecules in food products but may not be optimal for inorganic solid materials such as lunar regolith.

Thus, an industrial bespoke microwave heating apparatus has been designed to overcome the current limitations. Figure 1 illustrates a design of the apparatus which includes two pyrometers, one viewfinder window, and a cylindrical cavity with a flange for a vacuum pump. The ports can also be connected to a mass spectrometer, permitting extraction and analysis of volatiles while specimens are heated. Volatiles in regolith can be extracted by heating the regolith between 300 and 900 °C [3, 5]. For example, a temperature of 700 °C is sufficient to obtain most of the H₂ and He [6]. Thus, the

apparatus could also be used for measuring the types and amount of volatiles which could be used for propellant and life support (e.g. water). The new apparatus would allow to (i) maximise microwave energy in a single hotspot; (ii) measure the surface temperature and phase change of specimens under a near lunar atmospheric condition with more accuracy, and (iii) heating specimens of lunar simulant rapidly to be sintered/melted. This first version of the apparatus does not support multiple frequencies; however, this feature is planned to be added in a future upgrade.



Figure 1: Bespoke microwave heating apparatus

Numerical Modelling: As complementary research of the lab-experiment, we have chosen COMSOL (version 5.3a), which has been used previously for a similar purpose [7]. COMSOL requires various parameters of material characteristics to simulate microwave heating phenomenon. The findings from the numerical modelling are (i) verifying the bespoke design of the cavity that could maximise microwave energy to heat specimens; (ii) understanding the sequence of sintering phenomenon by continual simulation of the surface and internal temperature of specimens; and (iii) identifying the different effects of sintering among frequencies in terms of the time and penetration depth.

References:

- [1] Lim, S., et al. (2016). *Additive Manufacturing*, 12(B), 216-230. [2] Lim, S., et al. (2012). *Automation in Construction*, 21(1), 262-268. [3] Anand, M., et al. (2012). *Planet. and Space Sci.*, 74(1), 42-48. [4] Lim, S., Prabhu V.L., Anand, M. and Taylor, L. (2017) *Adv. in Space Research J.*, 60(7), 1413-1429. [5] Ethridge, E. and Kaukler, W. (2012). *Concepts and Approaches for Mars Exploration*. [6] Crawford, I. (2015). *Progress in Physical Geography*, 39, 137-167. [7] Ethridge, E. and Kaukler, W. (2012) *50th AIAA Aerospace Sci. Meeting*, AIAA2012-0801.